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WARFIGHTER'S EDGE:
Using Intelligent Agents To Solve Warfighter Problems

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Abstract

One of the most pressing problems on today's battlefield is the inability to locate and destroy the enemy's theater missile capability. Although the battlefield is awash with data with more sensors on the way, it may be ineffective and even detrimental unless the data can be transformed into information that can help end the conflict sooner and at less cost to our forces. Improving our forces' capability to locate and destroy the enemy's theater missile launchers and infrastructure would significantly contribute to shortening the conflict. This paper describes the results of using intelligent agents, i.e., smart software, to transform the constant stream of battlefield sensor data into information to aid those charged with locating these critical mobile targets (CMTs) and their infrastructure. The technology appears to be applicable to a number of battlefield areas as well as to the military infrastructure.

The presentation will provide a technical overview of intelligent agent architecture, a demonstration based on existing joint experimentation data and a quantitative evaluation of the agents' performance.

Preface

The Warfighter's Edge is an initiative being carried out by the Institute for Defense Analyses (IDA) in Alexandria, Virginia. It includes a number of tasks, many of which are mentioned in this paper. The Joint Advanced Warfighting Program (JAWP) supported the initial effort.[1] The IDA team on this initial effort included Dr. Lane B. Scheiber, Project Leader, Dr. Ronald A. Enlow, Mr. John F. Sandoz, Mr. Michael H. Anstice, and Mr. E. "Randy" Smothers.

INTRODUCTION

In 1999 and 2000, the Joint Forces Command (JFCOM) conducted human-in-the-loop (HITL) experiments to identify key issues affecting the success or failure of the attack operations capability of our Theater Missile Defense. The data from these experiments were also used to address the question as to the degree to which intelligent agents might aid operators responsible for locating and destroying CMTs. Using only data available to an operator's PC display, intelligent agents, operating at 20 to 100 times real time, combed through massive amounts of sensor input each time the data were updated—every 30 seconds in these experiments. The agents rapidly sorted the more than 10,000 civilian and non-critical military vehicles, which move about the 350,000-square-kilometer battlefield, from the enemy's missile transporter/erector/launchers (TELs) and missile transporters. Knitting together track segments of the vehicles and processing

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[1] *Intelligent Agents for the Warfighter*, IDA Document D-2617, is soon to be published.

relevant data, the agents were able to quickly and accurately find, report, and plot the hide, reload, and forward operating base FOB sites on a dynamic map display within milliseconds of the time of the sensors' reports. In addition, they did this using less than 1 percent of available data. The map display, maintained by the agents, also shows the CMTs' current locations and the routes they traveled as well as the status of the TELs, i.e., loaded or unloaded.

Intelligent agents are software programs that carry out functions, which, if done by a human, would be considered to exhibit intelligence. The functions they carry out, in general, are directed toward very specific areas. This is considerably different than the general concept of artificial intelligence, which had much grander goals in the '60s and '70s, but, for the most part, was unable to reach them.

This paper reports on work done in applying intelligent agents to warfighter problems. Although there is no shortage of data obtained on and off the battlefield and future plans call for even more data to be collected, our ability to use this amount of data in the decision-making process is lagging significantly behind our ability to collect it. The Warfighter's Edge effort is directed toward helping to solve this problem. Specifically, it is directed toward supporting humans in making decisions, not replacing them. It does so by taking advantage of functions humans do well and supporting them with the functions done well by computers.

The paper is divided into two parts: the experiment and the next steps. The first part describes the experiment that was conducted, the reasons behind it, the constraints under which it was conducted, and the results derived from it. The second part describes some ways the results are being used to develop an operational capability and to support areas other than the time-critical-targets problem examined in the experiment.

THE EXPERIMENT

Background

The Joint Forces Command (JFCOM) J9 is charged with carrying out joint experiments. The current scope of experimentation includes large human-in-the-loop (HITL) simulations (e.g., Unified Vision 2001), large field exercises (e.g., Millennium Challenge 2002) and smaller Limited Objective Experiments (LOE). The LOEs are designed with a deliberately restricted focus and may use data generated in previous experiments to investigate significant but smaller scale problems. The effort reported herein was an LOE, which made use of data generated in the HITL simulation experiments conducted in 1999–2000, referred to as J9901. To understand this LOE, it is necessary to first understand certain elements of the J9901 experiments.

The detection, identification, and destruction of critical mobile targets (theater ballistic missiles, cruise missiles, surface-to-air missiles) continue to be some of the most pressing problems on the battlefield. Various agencies of the Services and the Department of Defense (DoD) have continuously studied the conduct of attack operations against theater ballistic missiles (TBM) for more than a decade. Most recently, JFCOM sponsored two joint HITL simulation experiments, J9901 (1999-2000) and Attack Operations 00 (2000-2001) over two time thresholds (2015 and 2007 respectively). The experiments sought to use advanced sensors; command, control, communications, computers, and intelligence (C4I); and weapons to address the TBM threat. Both experiments were focused on attack operations and implemented versions of a Joint Critical Mobile Targets Cell (JCMTC) as part of the advanced C4I component of the experiment.

Two overall conclusions emerged through examining operator performance. First, despite an advanced computer interface, the Plan View Display (PVD), JCMTC operators generally experienced considerable difficulty in locating upper echelon targets such as transporter-erector-

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launcher (TEL) hide sites, TEL reload sites, and forward operating bases (FOBs). Second, in those areas in which operators were enabled with automated decision aids, such as weapon/target pairing tools, performance was enhanced. When automated assistance was not provided (such as locating upper echelon activity, e.g., reload sites), their performance was marginal. Given the vast amount of information (detections, tracks, launches) that operators must geographically correlate, it appeared to IDA that intelligent agents might provide the necessary enhancement to operator performance. IDA conducted a survey[2] in 1999 to determine the state of intelligent-agent development and implementation within the Services and agencies. No near-term solutions involving intelligent agents were identified. IDA then proposed the LOE experiment reported herein, and JFCOM J9 and JAWP provided the sponsorship.

Operational Concept

The Red Force Operational Concept used in the J9901 experiment is as follows. At the beginning of the conflict all TELs are loaded and in hide sites. At a particular point in time, which is different for each TEL, they come out of hiding, move to a launch site, and fire. After firing, they very quickly move to another hide site. Again, after a variable amount of time, each of the now empty TELs moves to rendezvous with a missile transporter (MTT), which is coming from the FOB with a new missile for the TEL. After a period of time, which includes the time required for reloading, the loaded TEL moves to another hide site, and the MTT returns to the FOB. After another variable amount of time the process starts again.

As noted above, the data used in this LOE are essentially that generated in the J9901 HITL simulation experiments. Some important things to note are the ratio of clutter (i.e., civilian) vehicles (10,000) to the number of military vehicles (about 360). Also, the size of the battlefield, which is approximately 350,000 square kilometers, and the duration of the conflict, which is 24 hours, should be noted because they relate to the results.

The sensor suite included a constellation of 24 satellites each equipped with strip and spot Synthetic Aperture Radar (SAR) as well as high and low resolution Moving Target Indicator (MTI) radar. These satellites were augmented with 12 Global Hawk-like uncrewed aerial vehicles (UAVs) equipped with either SAR or MTI radar. There were 10 pre-deployed area ground sensors (unattended ground sensors) and a DSP-like launch detection capability. The simulation of the sensor suite used in the J9901 experiments [Simulation of the Locations and Attack of Mobile Enemy Missiles (SLAMEM)] batched the detections, processed the detections through an automatic target recognition (ATR) algorithm, and utilized an elementary tracking capability to produce the data provided. The ATR classification algorithm did not provide an identification per se. Rather, it provided a sequence of 12 classification probabilities, one for each of the potential vehicle classes, which include short- and long-range TELs, short- and long-range MTTs, petroleum, oil and lubricants (POL) vehicle, buses, small trucks, large trucks, cars, etc. The classification probabilities were updated as subsequent detections were associated with the appropriate track segment. The update process utilized a Baysian algorithm.

Thus the data provided for this experiment consisted of sensor updates (hits) on vehicles on the battlefield. Each hit record contained the associated track segment, the time and location of the hit, and the set of 12 classification probabilities associated with that sensor hit. However, the simulated ATR that provided the track segment data required somewhere on the order of 15 to 20 hits on a vehicle for the true vehicle type's probability to become sufficiently dominate that an operator could identify the type of vehicle actually being observed. In many cases, the track

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[2] *The Commander's Edge*, IDA Document E-2475, July 2000.

segments did not last that long and, therefore, a great deal of the data was found to be of no value (see the Results section).

Figure 1 shows the operational concept in terms of the sensor hits and track segments. For example, at the lower left of the figure, the first hit in track segment 1 is labeled P11. It has associated with it the 12 probabilities from that one hit. The second hit on that track segment, labeled
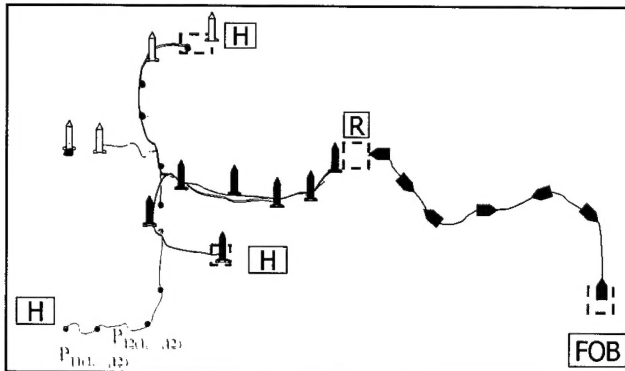

Figure 1. Operational Concept in Terms of Sensor Hits and Track Segments

P12, has the 12 updated probabilities reflecting the perceived vehicle classification of the second hit. Continuing along that track segment one can see that it contains 5 hits, each having its own sequence of the 12 probabilities. At this point, the track segment ends and a new one is started. Such a break may occur if the vehicle stopped for a period of time (while being detected by a MTI mode radar), was hidden from the sensor because it moved behind something, or traveled into an area outside the sensor's field of view, or if the sensor moved on to look in a different area. Later, the original sensor (or another sensor) may again acquire the vehicle. In this case, a new track segment would be started. When a new track segment is started, the ATR reinitializes, and the classification effort begins all over again.

Following the second track segment brings one to a firing. Firings are detected by the DSP-like sensor and these data do not contain any information on which vehicle (or track segment) actually did the firing. The agents must derive that information. When a TEL fires, it very quickly moves (within 3 to 5 minutes) to yet another hide site. If a sensor observes this movement, a new track segment with its associated probabilities would be started. The track segments in the figure show the empty TEL rendezvousing with the MTT, being reloaded, and moving to another hide site while the MTT returns to the FOB.

Figure 2 shows a partial Excel spread sheet with some experiment data associated with each hit on a vehicle. As described above, these data include the track (segment) ID, the last detected position of the vehicle, and the probabilities that are associated with that hit on the vehicle.

Operators in the JFCOM experiments used a computer workstation known as advanced plan view displays (PVDs) to display the data shown in Figure 2. The PVD provided the operator with an extensive menu of displays, views, filters and tools.

Figure 2. Track Segment Data

The PVD options were customized for the specific operator roles and were also the communications interface to sensor and attack system models. The tactical area is displayed in the upper right corner of the PVD. An example of this is shown in Figure 3.

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In this figure, yellow squares display the locations of each vehicle being observed by the sensors. Each square is an active link to additional information. By clicking on one of the yellow squares, the operator can obtain various types of information—the most operationally useful of which is the estimated vehicle type (classification) as last derived by the simulation (an example is shown in the figure). As new sensor information arrives and is processed, the track locations shown on the display and the associated classifications are updated. The operator can also manually augment the display to show tactical information that he may have derived or been given. Some of those indications (e.g.,

Figure 3. View of Tactical Area of PVD

launch points, suspected FOBs, suspected TEL decoy locations and SAM threat rings) are shown in here. However, they do not move as the vehicles move on the display.

Objective

The objective of this LOE was to take a set of the J9901 vehicle track segment data and to investigate the potential for intelligent agents to be able, in real-time, to transform this data into information containing the locations of the TEL hide sites, the reload sites, and FOBs. If made available to operators, this information could potentially lead to the destruction of enemy missile infrastructure and a rapid cessation of the tactical ballistic missile threat portion of the conflict. In addition, information about the TELs and their hide site locations could be used to:
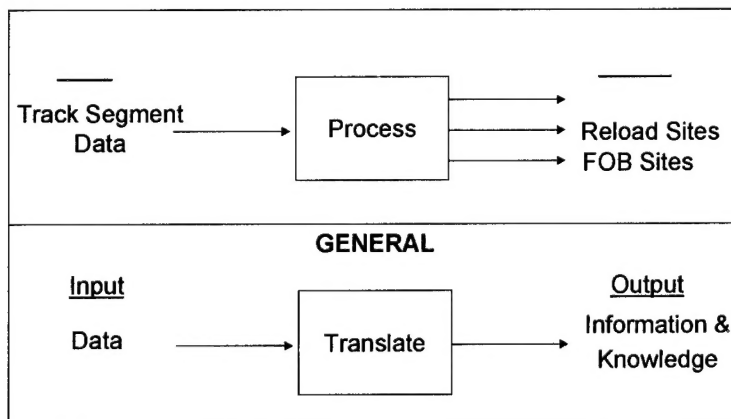
- Aid in destroying launchers before they can launch,

- Follow launchers that have already launched their missiles (empty TELs) to reload sites where they could be destroyed along with the MTTs and the other vehicles that are part of the reload process, or

- Follow those vehicles back to the FOB and destroy the FOB directly.

Figure 4. Objective

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Since one of the Red Force's objectives was for each TEL to launch three times a day, if FOBs and reload sites were destroyed, the conflict would end much more quickly than if one is limited to simply killing TELs with the remaining TELs still able to continue firing.

Data are being accumulated everywhere: on the battlefield, in the strategic world, in the Services and DoD in general, in industry, and even in our own lives. This accumulation is not expected to slow in the near future. If anything, the rate at which we are accumulating data is expected to increase. This LOE is a specific case of the more general problem of translating data into information that we can use to make better decisions and to make them more quickly.

Approach

The approach used in this LOE was to examine the potential ability for intelligent agents to monitor track patterns of vehicles on the battlefield along with the launch data provided by the DSP and to extract enough information from these data to comprehend the meaning of track patterns and their associated vehicle operations in order to locate TEL hide sites, reload sites, and FOBs. Thus, following the objective of this LOE, intelligent agents were developed to take the data shown in Figures 2 and 3 and translate it into information and knowledge that the warfighter can use to more easily and quickly carry out his or her mission. An example of this is shown in Figure 5, which is a snapshot of the intended output of the intelligent agents. Shown are

Figure 5. Example of Intelligent Agent Output

examples of hide, reload, and FOB sites that the agents have uncovered along with decoys and missile firings. The agents also draw the road network, in real- time, as the TELs and MTTs move from one position to another. The words and arrows have been added to aid the reader.

The Process

Figure 6 provides an overview of the experimental process. Two sets of data were provided for the LOE. One set was sensor data and the other was ground truth. As shown, only the sensor data, constructed as previously described, was provided to the intelligent agents. The agents, running in parallel, process the data looking for the FOB, reload, and hide sites. In general, when an agent finds a site location, it provides this information to the display, which makes it available to the operator. These are also the data used in the

Figure 6. Experiment Process Overview

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demonstration. The second set of data, the ground truth, is only used in this experiment to calculate how accurately intelligent agents are able to locate the three different kinds of sites. The output of this analysis is provided in the results section below.

Figure 7 shows details of the agent process. The underlying concept is to transform the data entering the process (the vast amount of data has been found to be difficult for humans to cope with in real-time) into information with which humans can more easily achieve their objectives. The process is based on a modular concept, which uses a number of agents, each of which has a specific role. However, only those agents that have rules derived from knowledge of how the Red Force operates are referred to here as intelligent agents. The tasks associated with each of the agents are described in the following.
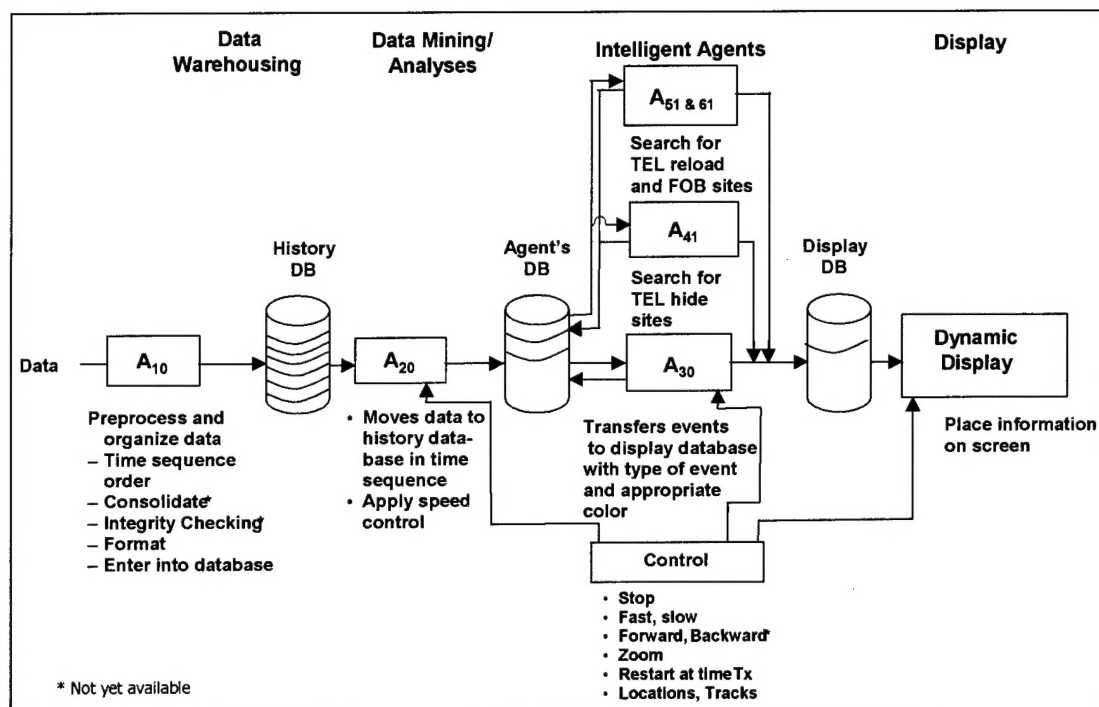
Figure 7. Detailed View of Agent Processes

Starting from the very left side of the diagram, the first agent (shown here as A_{10}) is set up to input and organize the data. In general, when setting up this type of process, one must assume that the data most likely will not be in the desired format. There is also the possibility that the data will be coming fr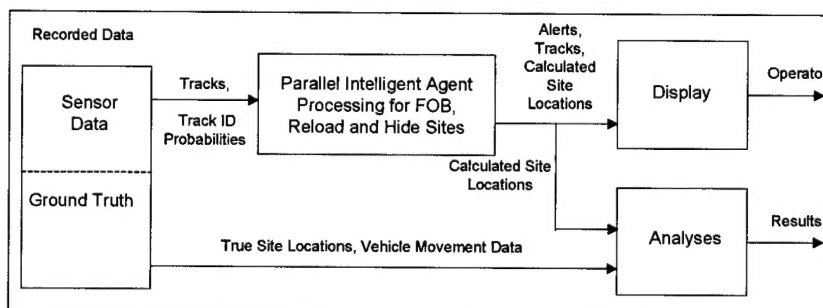om different sources, each with its own unique format. Therefore, some processing will be required. This could be somewhat complicated depending on the characteristics of the data streams involved. That is, A10 could actually be a number of different agents, each dedicated to a different input task. On the other hand, in an experiment such as this where the data are provided as a collection of files, some of the processing could be done manually whereas, in a normal real-time process, the data would be collected, fused together, and entered into the history database as it became available. Thus, in general, the first agent transforms the data from different sources into the same format. The agent orders the data according to time sequence and enters the result into a database (the history database).

A database structure was used in this LOE for two reasons. First, the data have a natural database structure. That is, there are a large number of individual sensor inputs, each of which looks like a record in a database. Each individual sensor inputs has a number of entities that each

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appear as a field in a record, for example, the time the sensor saw the vehicle, the sensed location of the vehicle, and the 12 probabilities of vehicle type. Second, the type of agents used here can easily be written in database language, and the process executes well inside its potential real-time requirement on relatively inexpensive PCs.

The second agent (shown here as A_{20}) looks at the data being enter into the history database and determines whether or not the intelligent agents might be interested in these data. If the agent's rules indicate that intelligent agents would have some interest in a specific sensor input, it copies that data to the agent database. In this LOE, the data were entered into the history database at the start of the agent process. So the second agent was able to move data into the agents' database as fast as the intelligent agents could process it. This allowed the process to run up to 100 times faster than real-time.

Three intelligent agents are shown here (A_{41}, A_{51}, and A_{61}): one for finding TEL hide sites, one for finding TEL reload sites, and one for finding FOB sites. Each agent has a set of rules that it uses in an attempt to derive information from the data in the agent database. When the A_{20} agent places new data in the agent database, each intelligent agent examines the new data along with all data previously entered in the database to see what additional information about the sites it is programmed to look for might be derived from the total data now available. When an agent finds information on a potential site, it moves that information to the display database. The display processor picks up the information from the display database and places it on the display's screen for the operator to observe.

A number of other processes are going on simultaneously. For example, a control process allows one to stop the agent processing, to slow it up, to zoom in and out, and to place messages on the display to alert the operator to an event an agent has detected. Also, $Agent_{30}$ moves some data directly from the agent database to the display database. An example of this is the firing of the missiles. Although these data are used by the intelligent agents to determine which TELs are loaded and which are not, it is also of direct interest to the operator.

Intelligent Agent Rules

A study of the tactics, techniques, and procedures (TTP) used by the Red Force indicates the following. TELs and MTTs collocate only to reload the TELs. They are very large and rather slow moving vehicles. They are prime targets. To have them together unnecessarily would constitute a significant risk of enemy attack. Thus, a basic rule for the hide site agent is to look for *TELs stopping for a period of time without MTTs in the area.*

As noted above, in the experiments from which this LOE's data were taken, in order to reload a TEL, *both the TEL and the MTT must stop at about the same time and in about the same area for a sufficient period of time to reload*. Either could be there longer, but two criteria are against it. First, any undue exposure is to be avoided. Second, the TTP calls for the TELs to launch three times a day. Any unnecessary delays run counter to this criterion. Thus, this became the rule for the reload site agent to use to locate the reload sites.

According to the TTP, the Red force did not locate TELs in or around FOBs. On the other hand, the MTTs frequent the FOBs to pickup the new missiles to reload the TELs. Thus, the FOB site agent looked for *MTTs that stop or start in locations that have no TELs in the vicinity*.

In order for the agents to derive creditable information on sites of interest, each one must knit together a significant amount of disparate data. To test the robustness of the agents in carrying out this function, the agents were not given any information on the battlefield itself. All information provided on the display is generated from the agents knitting together the input sensor data.

Some Agent Strategy

Figures 8a and 8b show some of the strategy in the development of the agents—specifically the FOB agent. In this particular version of the agent, the 5th sensor input was used with look back to the origin. The agent's strategy is as follows: $Agent_{20}$, as shown on Figure 7, looks at each one of the inputs as the sensor data comes into the process and computes the sum of the classification probability of the vehicle being a short- or long-range TEL (PT) plus the probability that the vehicle is a short- or long-range MTT (PM). If the sum of the probabilities is less than 50 percent, the agent does not put that sensor data into the agent database (as indicated by the circles with slashes in them). Only when the combined probability is 50 percent or more does $Agent_{20}$ put the data into the agent database. It should be noted that the 50 percent value is a variable parameter that can be adjusted for different situations.
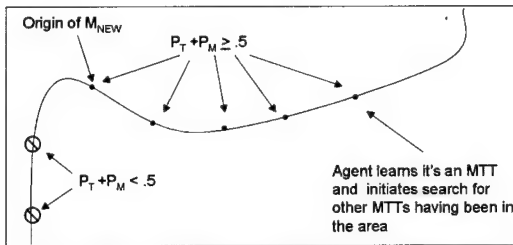

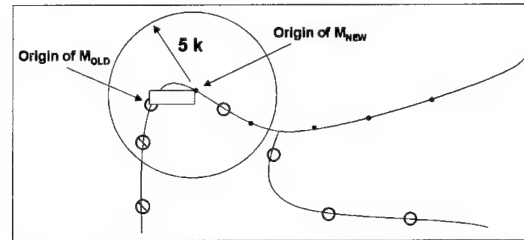**Figure 8a. FOB Agent Checking 5th Sensor Input**

Figure 8b. FOB Agent Searching for Other MTT Tracks Starting or Stopping in Area

The first question the FOB agent must address is whether or not the vehicle is an MTT. Since it is known that, in general, the classification probabilities associated with the early sensor input of a track segment will change considerably over time, many of the initial sensor inputs on a track segment are of little value in determining the type of vehicle being tracked. The question then becomes: Which sensor input should the FOB agent use to determine if the vehicle is a TEL or an MTT? The FOB agent shown in these figures uses the 5th sensor hit of that portion of the track segment entered into the agent's database. The number is a variable parameter and can be readily changed for different situations. It could even look at each input and take further action only when the probability of being an MTT is at least equal to a preset value (actually another variable), or it could use two or more inputs to test against the preset value.

In this example, when the 5th sensor hit on the track segment arrives, the FOB agent looks to see if the dominant classification probability is associated with an MTT. If it is, then the question becomes: Has at least one other MTT started or stopped in this same area—the criteria for identifying the location of a FOB. As shown in Figure 8b, the FOB agent looks back to the original input location for that track segment (as recorded in the agent's database) and initiates a search for other MTTs. The current FOB agent uses a circular search pattern. In the example given, the radius of the circle is 5 kilometers, which is another variable parameter that can be modified to meet other situations. If it finds another MTT track segment that started or stopped in the same area, its starting or stopping point is located. The starting and/or stopping points of the two track segments are used to define an area (shown here as a rectangle) that potentially contains the FOB. This area, when combined with (i.e., placed on top of one another) areas derived from other indications generated by the FOB agent can be viewed as a three-dimensional figure, the density of which provides an indication of the likely location of the FOB.

Although it was not required in the current experiment, the agent could go back to $Agent_{20}$ and ask for additional track data on this track segment to find the original starting point for the

segment as indicated by circles with slashes in them. This could possibly give even more accurate location information for the FOB. But since the information given by the current FOB agent configuration is satisfactory for the operator in the current situation to initiate his next process, it was not necessary to give the agent that capability.

As an additional means to cope with the uncertainty associated with the input data, the agents consulted each other's results. That is, when an agent (say Agent A) derived information on the location of the type of site for which it was responsible, it looked to see if the other agents had already identified that site as a different type. If another agent (say Agent B) had identified the site as a different type and had done it with sufficiently high probability, then Agent A would differ to Agent B. Otherwise it would not until one of them had a substantial advantage.

Results

Location Indications

Figure 9 shows the results of the agents' attempts to pinpoint the locations of the different sites. The FOB agent provided 347 indications, of which 341 correctly identified an FOB site. That is, more than 98 percent of the indications by the FOB agent were correct (see left bar). The average distance from the true location (centroid) of the FOB sites to the locations indicated by the agent was 1.6 kilometers. About 1 percent of the time the sites identified as FOBs were really reload sites. An analysis of the track segment data reveals that this was caused by the classification probabilities.

Figure 9. Example of Agent Results—Location Indications

That is, according to the classification probability associated with the sensor inputs, all of the vehicles entering or leaving the reload site during the period of interest were MTTs, when in fact some of them were TELs. This caused the FOB agent to believe that the reload site was really an FOB site. Only in 3 cases did the FOB agent point to a location that did not have a site of interest within 10 kilometers.

There is a significant relevance to the 341 correct indications. Since there were only four FOB sites, then on the average, there are about 85 indications per site. These indications can be viewed as a three-dimensional stack of the areas associated with the indications. This stack forms a density function, which may provide added insight as to the likely location of the FOB site.

The second bar shows that the reload agent provided 726 indications of the locations of reload sites. Of them, 705, or about 97 percent, where correct. The average distance from the reload site indicated to the true reload site was about 1.4 kilometers. This is sufficient accuracy for targeting area weapons such as ATACMS. The sites that were improperly indicated were, in general, TEL hide sites. In these cases, data indicated that a MTT had stopped near a hide site, which caused the reload agent to mistakenly identify that area as a reload site.
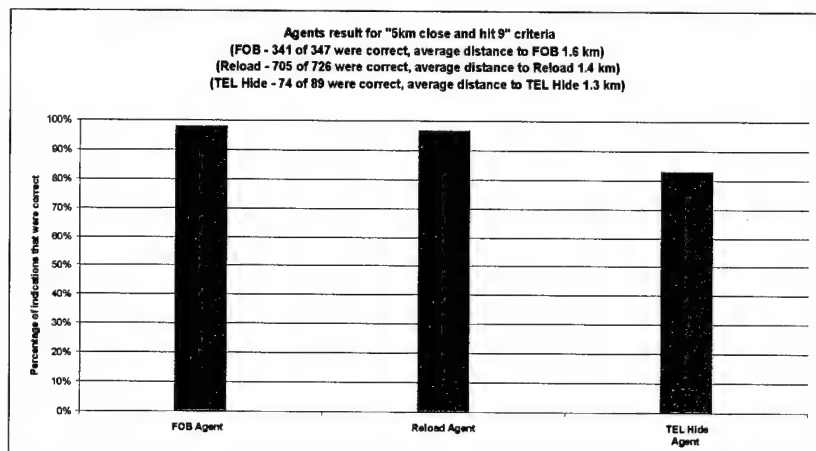
The third bar shows the location indications for the hide site agent. The hide site agent provided a total of 89 indications, 74, or about 83 percent, were correct. The average distance from the hide site indication to the correct site location was about 1.3 kilometers. The sites that were incorrectly identified were TEL decoy hide sites and real TEL launch sites. In this experiment, the sensors could not tell the difference between TEL decoys and (real) TELs. Thus, the only way to ascertain which was being observed was that real TELs fired and decoys did not.

Results

Distribution by Time

Figure 10 shows the indications made by the FOB agent during each hour of the 24-hour timeframe of the conflict. As can been seen, the agent is only able to provide meaningful indications starting at the 5th hour at which time it provides 23 indications. This is because the TELs are loaded at the beginning of the conflict and are in their hide sites. When they come out of hiding, they move into a firing location, fire, and then move to another hide site. Only after spending time in the new hide site do they come out and meet up with an MTT to reload them. Since the FOB is at the upper echelon of the logistics chain, there is no activity for the agent to analyze until this period of time has passed. It is also interesting to note that by
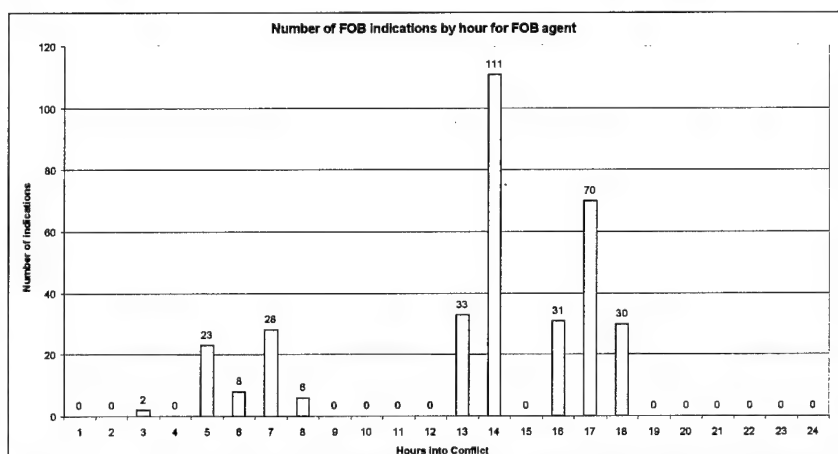

Figure 10. Example of FOB Agent Results—Distribution by Time

hour 5 all of the FOB sites have been identified with sufficient accuracy to begin collecting targeting information. The implication here is that if all of the FOBs could be targeted for destruction shortly after hour 5, the Red OPFOR would not have any missiles to fire other than those currently on the TELs and MTTs. Thus, this part of the conflict would come to a close very soon if the launch rate were to be sustained.

Results

Additional

A number of different agent configurations were examined. Although most agents did rather well, some obviously performed much better than others. However, all were accurate more than 50 percent of the time even when only 20 percent of the data were used, i.e., when the agents only received every 5th input from the sensors. As described later, additional trials are underway to examine the effect of changes to the parameters used in the model that generates the track segment data.

The Demonstration

The object of the demonstration is to show how data shown on the operator's display (Figure 3) can be transformed into the information shown in Figure 5. The demonstration begins with only the latitude-longitude grid showing. The agents derive and draw everything else. That is,

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the agents are given no information about the battlefield—i.e., no Intelligent Preparation of the Battlefield (IPB).

The demonstration can be run at various speeds. Since it covers a 24-hour period, it is generally run at about 360 times real time, which takes about 4 minutes. As the demonstration proceeds, hide, reload, and FOB sites are identified by color (purple, magenta, and green, respectively). The physical size of a particular site identified by an agent grows as the agent continues to develop information about the site. This growth is especially true for the FOB and reload sites, which are not points but areas. As the TELs and MTTs move, the agents draw the road network on which they are moving.

Although the sensors cannot distinguish between real TELs and decoys, one can see the decoys in the demonstration. These are TELs that do not fire or meet with MTTs. Some are in the open by themselves, but others are intermingled with real TELs. One will also observe data anomalies, such as vehicles that are suddenly in an obviously wrong position and return to their correct position a bit later. Although this is troublesome for the human, one can see that it does not trouble the agents at all.

The display has a number of features that can be demonstrated, such as the ability to be stopped and restarted, the ability to zoom in and out, and the ability to provide alert messages for the operator.

Observations

A number of observations can be made at this point. First, the agents can continuously search massive amounts of continuously changing data while looking for correlating events. In the experiment, new data were incorporated into the database every 30 seconds (in real-time). When new data were entered, agents repeated all calculations to see whether the new data provided any new insights as to the locations of the sites for which they were looking. One observation made from the demonstration is that the agents are able to convert data into useful information in real-time. Further, instead of simply having vehicle-movement data as presented on the operator's screen in the HITL simulations, the agents are able to provide information such as the infrastructure associated with the Red missile force as well as the status of the force elements, e.g., whether or not the TELs were loaded. Also, one can see in the demonstration that the agents are able to easily contend with data anomalies, that is, indications that a vehicle is at a particular location one moment and at a much different location at another moment. These anomalies caused the human operators considerable difficulty in the J9901 experiments.

The agents are also able to call the operator's attention to occurrences of correlated events as they occur. One example, shown in the demonstration, is the alert messages that are available to the operators. These messages provide an indication that an event of interest has just taken place. Furthermore, the agents' display provides the opportunity to predict some events such as reloads. When an MTT is approaching an empty TEL, a reload is very likely to occur in an area somewhere between their current positions. This can provide operators with valuable lead-time in which to task and maneuver attack platforms.

In these experiments, there were a significant number of TELs and the TTP used by the Red Force called for each TEL to fire 3 missiles a day. If the Blue Force is only able to kill the TELs, the conflict could last for a considerable length of time. On the other hand, using the information agents provide on enemy infrastructure could enable the Blue Force to destroy FOBs and reload sites. This capability would deprive the TELs of the opportunity to reload, which, in turn, could potentially shorten at least this part of the conflict.

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Another significant observation is that, although the sensors provided a great deal of data, the agents only used 0.6 of 1 percent of the data. Of total data gathered, 99.4 percent contributed nothing to the information and knowledge the agents generated. It is interesting to speculate the effect of this additional information on the operators as well as the communications systems.

NEXT STEPS

Two areas of current interest are the development of the current intelligent agents for operational use and the examination of other areas of potential application of intelligent agents.

Operational Use

The results of this LOE show the potential for intelligent agents to aid in solving the time critical targets problem. The next question is what is necessary for intelligent agents to be used on the battlefield? Some of the issues are addressed in the following.

The robustness of the agents is of particular interest. The data from the J9901 experiment used in this LOE had a fixed set of sensor and ATR characteristics. A set of experiments is currently underway to examine the ability of intelligent agents to cope with changes to the frequency at which the track segments are updated, the characteristics of the ATR as well as no ATR, and the factor used to correlate the ambiguity generated when the tracker is faced with multiple detections in a small area.

As already noted, it is also possible to improve the current agents' processing to reduce the error associated with the location of the sites as determined by the agents and the actual site locations. More information is available in the data, but the agents need to be configured to be able to use it. However, in the current use of the intelligent agents, operators believed that this was not necessary because the agents already give them sufficiently accurate information for them to take the next step in the attack process. On the other hand, it is possible for agents to help operators with this next step. One example involves the task of requesting additional sensor data to be used to attack the targets, to evaluate that new data, and to provide sufficiently accurate information, in near real-time, with which to attack the targets. This assumes, of course, that the applicable information is contained in the newly collected data.

Another topic is for the agent to be able to fuse sensor data. This is being examined in another one of our current efforts.

The third area is that of data purging. In a conflict that lasts any amount of time, it would seem reasonable that one would not be able to store and recall information in great volumes. A great deal of information stored in the history database undoubtedly would never be used, for example, track segments that are known to be cars, small trucks, and other vehicles of that type. Unless there are some correlating facts, these are probably not of interest and, after a period of time, could be deleted.

The concept of agent learning needs to be further developed. This comes about because the Red Force will generally change its TTP—if not when it's wining the battle, then certainly when it's loosing. Therefore, the agent needs to be modified to include adjustable parameters where they are currently fixed. Another area involves awareness that humans generally have but current agents do not. For example, humans often sense change—a new sound, a change in color, or a change in a scene being viewed. This needs to be incorporated since the agents will probably be the first entity to observe enemy changes. One may want to set up one or more agents to specifically look for indications that the enemy is undergoing changes and bring this to the operator's

attention. The operator could then adjust the other agents or possibly have these new agents automatically make adjustments to the other agents.

Another topic is teaching agents. Because the enemy is going to change his TTP, agents need to be able to learn from the operators as well as from their own indicators. So the agents must be programmed so that operators in the field can modify the agents' capabilities. Thus, a method must be developed for operators to communicate with the agents to bring about this change.

Another issue is measures of effectiveness. After seeing the demonstration, most people feel that the agents can help operators find and attack not only TELs but also their infrastructure. A way needs to be developed to compare the effort done by the operators alone with that done by the operators when assisted by the agents. To accomplish this, it has been proposed that an additional experiment be done. The first set of trials would involve humans viewing the sensor data using only the type of display used in the J9901 HITL experiments. The second set of trials would, in addition, provide the operators with the real-time output of the intelligent agents. The difference in the measures recorded would provide an indication as to the benefit provided by the agents.

Additional Applications

In the many discussions we have had with a wide variety of military organizations, it is clear that there are many areas of potential application of this technology. Some examples are Combat ID, Joint Suppression of Enemy Air Defense (JSEAD), intelligent preparation of the battlefield (IPB), strategic weapons tracking, support for future combat systems, drug interdiction, and sensor assessment. Some of these efforts are already underway, some have been formally proposed, and some are in the concept development stage.

In certain respects, the combat ID and drug interdiction problems are very similar to that of TCT. For example, they both benefit from vehicle history, such as where did it come from, what route has it taken, and what has it done along the way? It's certainly possible that intelligent agents can help to solve these very pressing problems.

The J9901 effort was done without enemy air defense. If enemy air defense were to be played in the future human-in-the-loop simulations, operators would have to contend with this in addition to the effort of finding and killing critical mobile targets. Intelligent agents could help reduce the impact of this by helping to track enemy mobile air defense weapons. With regard to IPB, intelligent agents are already mapping out much of that, as can been seen in the demonstration. A task to aid in the tracking of strategic weapons is already underway in support of STRATCOM. Future Combat Systems is essentially a task that looks at the same timeframe as J9901 but adds more sensors and reduces ATR. This would appear to provide humans with a much more difficult challenge than in J9901 because they would have more data and less ability to understand what that data means as far as having an ATR assembling it into track segments for them. The question here is whether intelligent agents can help them sort through the data in ways that can make up for lost ATR capability. An effort to address this issue is already underway.

Intelligent agents may also be able to assist with other problems, for example, the assessment of contributions of new and modified sensors in both their acquisition and employment. These are significant, ongoing problems in both the strategic and tactical arenas that are not likely to abate anytime soon. As already seen in this LOE, one can look to see what use the agents are making of data provided to them. If a new sensor is added to a suite or an existing sensor is modified, one could look to see the degree to which the agents, modified if necessary, actually make use of the data from the new or modified sensor.

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Another area of interest is that of identifying characteristics that make applications potentially amenable to intelligent agent support. The final area is that of agent development methodology. If indeed one were to have an ongoing number of agent efforts, then it would seem that a methodology to permit the efforts of one project to be used to support another would certainly be in order. Efforts in this area are also already underway. In particular, the display on which the agents place their output is being generalized so that it can be used in many, if not all, of the prospective applications.

The Challenges

It is apparent that intelligent agents can help in many areas. The challenges are numerous. One of the first is to identify the type of information or knowledge that would be most beneficial to the organization. Another is to determine the data that are or could be available. Although these issues may seem to be easy to address, they normally are not. They require in-the-box as well as out-of-the-box thinking. By in-the-box thinking we mean the current concept—how it is done today and steps that might make it better. Out-of-the-box thinking is usually the difficult part. For example, if things were done differently, what data might be made available? Who would collect it and how? Would the data that could be collected add significantly to the information and knowledge currently being provided? Are new sensors or modifications to current sensors required? Does the technology to support the necessary improvements exist or does it have to be developed? Are currently available data not being used; do users even know about the data? If additional or better data were available, how would this best contribute and what would be the impact?

As can be seen, many questions remain to be addressed besides those associated with the design and development of the intelligent agents. Thus, the real challenge is for all of us to examine the problems confronting the warfighter and to seek new approaches to overcome them.

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 2001	Final

4. TITLE AND SUBTITLE
Warfighter's Edge: Using Intelligent Agents To Solve Warfighter Problems

6. AUTHOR(S)
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5. FUNDING NUMBERS
DASW01-98-C-0067
BC-1-476

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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1801 N. Beauregard Street
Alexandria, Va 22311-1772

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Document D-2623

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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

One of the most pressing problems on today's battlefield is the inability to locate and destroy the enemy's theater missile capability. Although the battlefield is awash with data with more sensors on the way, it may be insufficient and even detrimental unless the data can be transformed into information that can help end the conflict sooner and at less cost to our forces. Improving our forces' capability to locate and destroy the enemy's theater missile launchers and infrastructure would significantly contribute to shortening the conflict. This paper describes the results of using intelligent agents, i.e., smart software, to transform the constant stream of battlefield sensor data into information to aid those charged with locating these critical mobile targets (CMTs) and their infrastructure. The technology appears to be applicable to a number of battlefield areas as well as to military infrastructure.

The document will provide a technical overview of intelligent agent architecture—a demonstration based on existing joint experimentation data and a quantitative evaluation of the agents' performance.

14. SUBJECT TERMS
intelligent agents, software, critical mobile targets (CMTs), Limited Objective Experiment (LOE), transporter/erector/launchers (TELs), missile transporters

15. NUMBER OF PAGES
16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMIT OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Unlimited